# THE IDENTIFICATION OF HAZARDOUS JOBS IN INDUSTRIAL PLANTS

A THESIS

Presented to

the Faculty of the Division of Graduate Studies

Georgia Institute of Technology

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Safety Engineering

by

Charles V. Culbertson

June, 1950

THE IDENTIFICATION OF HAZARDOUS JOBS

IN INDUSTRIAL PLANTS

Approved:

Date Approved by Chairman May 19, 1950

## ACKNOWLEDGMENTS

In determining the frequency rate credibility, invaluable assistance was given by Mr. W. V. Neisius, Department of Mathematics, Georgia Institute of Technology. Appreciation is also expressed for the guidance and advice of Professor W. N. Cox, Jr., Head of the Department of Safety Engineering.

# TABLE OF CONTENTS

## LIST OF FIGURES



## LIST OF TABLES

THE IDENTIFICATION OF HAZARDOUS JOBS

IN INDUSTRIAL PLANTS


## SUMMARY

The statistical analysis of injury rates using plant, departmental and job data is reviewed. Job data, though offering smaller exposures, yield more useful information for accident prevention purposes.

Standards are defined for determining when a job becomes a hazardous job. The degree of this hazard may be found by solving for the H-number. "H" is derived for lost-time frequency, first-aid frequency and severity. By computing "H" the more hazardous jobs, as regards all three injury rates, are identified. Recommendations are made for collecting the data necessary in the calculation of "H".

The credibility of "H" is the same as the credibility of the injury rate. A method is presented for determining the credibility of the frequency rate. It is proved that credibility is a function of frequency as well as of exposure. Consequently, extremely hazardous jobs may be studied with only a fraction of the exposure considered acceptable in the past. The credibility of the severity rate and of the first-aid rate is discussed.

The significance of the variation of the accident distribution from the Poisson distribution is accounted for. It is found that through certain adjustments and interpretations, accident statistics

based on a Poisson distribution may be analyzed profitably.

Several methods of overcoming the low credibility resulting from extremely small exposures are introduced.

## INTRODUCTION

The prevention of industrial accidents has consistently involved the statistical analysis of records of previous injuries. The breakdown for analysis and application varies widely. Plant and departmental breakdowns are commonly used. Less frequently the breakdown is formulated to include the responsibilities of each supervisor or foreman. Another less common analysis, one recommended at the President's Industrial Safety Conference of 1949, is by occupation.

When finer breakdowns of a given volume of data are used, the conclusions become less reliable because the number of man-hours of exposure is reduced. Also, however, with each finer breakdown, more specific and useful information about hazards is revealed. Departmental analysis discloses certain areas of hazard which would escape detection in the broader plant rates. Again, a breakdown by occupation reveals additional specific causations.

It is the purpose of this treatise to show the advantages of an analysis of injury rates by job, a breakdown of finer nature than those commonly employed. The word, "identification", as used in this thesis, means location or ascertainment. A method of determining the more hazardous jobs, and a quantitative analysis of the degree of hazard, will be introduced. The term, "job", as differentiated from "position" or "occupation", is taken from Shartle's[1] definition as "a group of similar positions in a single plant....There may be only one or there

---

[1]C. L. Shartle, <u>Occupational Information</u> (New York: Prentice-Hall, Inc., 1946), p. 11.

may be many persons employed in the same job". For such a division, since fewer employees are considered, small exposure in man-hours must be utilized. In the past it has been assumed that small exposures led to unreliable accident or injury rates. In a later section it will be demonstrated mathematically that in many instances -- especially as regards the more hazardous jobs with which we will be concerned -- a defined credibility may be attained with relatively short exposures.

The method of application of this fine breakdown will not prevent the small plant from obtaining beneficial results. However, the time required to develop these results will be longer. This time interval will be governed solely by the reliability of accident rates which shall be deemed acceptable.

The scope of any hazard analysis is a function of the homogeneity of the unit to be analyzed. Comparison of the frequency rates of different departments in a plant reveals little of use for accident prevention when the processes and hazards of the departments are different. Yet certain hazardous jobs may be common to many of the different departments. Analysis of these jobs, rather than of departmental performance, will direct the accident prevention program where it is most needed.

The technique to be presented is derived for application to a whole plant. Similar results can be obtained, however, by application to a group of similar plants, or to a single large division within one plant. The more hazardous jobs, considering lost-time frequency, severity and first-aid frequency rates, are defined and located in such a way that elimination or reduction of the hazards involved in these jobs will reduce the plant injury rates more than the elimination of any other hazards.

An attempt will be made to set up standards for defining and answering such questions as the following: When is a job a hazardous job?; how hazardous is the job?; how reliable is our measure of hazardousness? After eliminating certain hazards from a job how can we measure the reduced hazardousness? How accurate is this measure?

Supervisors will more readily accept specific, objective information on safety performance. They want to know exactly "where my crew or department stands". A yardstick for this measurement will be presented.

For a full understanding of the method to be introduced it is essential that the section on definitions be fully understood. Because the method is new, certain unfamiliar and precise definitions are unavoidable.

## DEFINITIONS

Standard definitions and terms are used where possible. However, it is necessary to create some new terms for complete understanding of the presentation. Definitions are grouped in this one section for reference.

Position: A group of tasks performed by one person.

Job: A group of similar positions in a single plant.

Occupation: A group of similar jobs found in several plants.

Hazard: Any phenomenon which potentially could be partly or fully, directly or indirectly responsible for an accident.

Hazardous Job: A job having any of the three injury rates (lost-time frequency, first-aid frequency or severity) higher than the corresponding plant rate.

Study: An investigation of a hazardous job by qualified persons for the purpose of eliminating all major hazards from that job.

Completed Study: A study is completed when the job is no longer a "hazardous job".

Hazardousness: The degree of hazard present in a job.

Most Hazardous Job: That job which would effect the greatest reduction in the corresponding plant injury rate when its study is completed, assuming the rates of all other jobs remain constant.

H-Number (or "H"): A number computed to measure the hazardousness. The higher the H-number, the more hazardous the job.

Lost-Time Frequency Rate: Number of lost-time injuries per million man-hours.

First-Aid Frequency Rate: Number of first-aid injuries per million man-hours.

Severity Rate: Days lost or charged per thousand man-hours.

Injury Rates: Any or all of the above three rates.

True Injury Rate: A rate computed from an infinite time interval.

<u>Credibility</u>: A measure of the probability that the true injury rate lies within certain defined limits of the computed injury rate.

<u>Lost-Time Injury</u>: An injury causing inability to work beyond the shift during which the injury was received, or any permanent injury involving a time charge.

<u>First-Aid Injury</u>: An injury causing no loss of time beyond the shift during which the injury was received.

## DEPARTMENTAL ANALYSIS VERSUS JOB ANALYSIS

As the scope of any accident analysis program is broadened, specificity must be sacrificed. If one department is found to have more than its share of accidents, emphasis is usually placed on safety throughout that department. Every supervisor is instructed to "clean up the hazards" and to control unsafe practices and conditions. The department is covered thoroughly with many relatively nonhazardous operations receiving undue attention.

The same hazards which caused this one department to have so many injuries may exist in all other departments, but to a lesser degree. Such hazards are easily by-passed through departmental emphasis.

A similar situation exists when one department continually maintains the highest injury rates. It soon becomes a marked department and frequently the majority of the safety efforts are extended to this one department over a period of years. Again the worst hazards may be completely overlooked in the other departments.

An oversimplified example of how efforts can be misdirected in gross breakdowns is in order. Department "A" may have twice the frequency rate of Departments "B", "C", "D", and "E". Assume the "hidden hazard" is in general rigging operations, and that Department "A" employs 20 riggers. The other four departments may employ 10 riggers each. Separately these four departments have half the frequency rate of Department "A", but collectively they will yield twice as many injuries, and from the same hazard that is drawing the focus of activity to Department "A".

Certain jobs are inherently more hazardous than others. A coarse breakdown of injury rates, such as by plant or department, only represents some unknown combination of job hazards in an unknown proportion. Using such data to determine where safety studies may be most effectively applied would be difficult.

Records pertinent to compilation of job accident data are discussed in another section.

Grouping similar jobs for separate study yields a homogeneity of operations that will not be found in departmental analyses. Repetitious causes are more readily determined. Training needs, process changes, and engineering analyses necessary for hazard elimination are more easily identified.

## IDENTIFICATION OF HAZARDOUS JOBS

The job itself usually determines the type of injury most frequently incurred. Some jobs are responsible for many first-aid cases while the possibility of a more serious injury may be remote. Other jobs involve hazards of a more serious nature, frequently resulting in lost-time accidents while yielding very few minor injuries. A third type of job, such as one liable to major explosions, may result in very few, but fatal injuries. Combinations of these three job "types" would result in a great number of classifications of job hazard types.

All three varieties of injuries, first-aid, lost-time and fatal, are costly to both employee and employer. Consequently all three types of injuries (no-injury accidents are excluded from this method because of the prevailing difficulties encountered in obtaining complete and accurate records) should be considered in any accident prevention program.

The standard A.S.A. frequency and severity rates are used herein (see page 6). The first-aid frequency rate will be defined as the number of first-aid injuries per 1,000,000 man-hours exposure.

Blake[2] and others recommend that first-aid cases be excluded from accident rate calculations. "Such inclusion creates an incentive (to both employee and supervisor) to let minor injuries go unreported, hence, untreated, and the consequence is (more) infections." This "inclusion" refers to a formal report, such as the foreman's accident

---

[2] R. P. Blake, Industrial Safety (New York: Prentice-Hall, Inc., 1943), p. 33.

report prepared for lost-time accidents. Such a procedure would admittedly be unwise. However, a brief record is conventionally maintained at the place of treatment (hospital, first-aid station, etc.) for all first-aid cases. By including the job title and the nature of the injury on this record the safety personnel would have ready access to the desired information. As implied by Blake, such rates should not be publicized or used to induce competition. It is of course not intended that any strict secrecy be practiced. Certainly the rates can be computed and the hazardous jobs determined without supervision becoming alarmed.

A "hazardous job" is defined as a job with an injury rate higher than the corresponding plant injury rate. The plant rate is taken as an arbitrary base for several reasons. Any plant will include a variety of jobs with considerable difference in injury rate between the safest and the most hazardous job. Obviously the plant injury rates will lie somewhere between these two extremes. As will be understood more clearly later, in measuring the degree of hazardousness there must be some reference point from which to measure. The plant rate, which actually represents the average of all job injury rates, is mathematically convenient and easily discerned.

Thus a job becomes hazardous when any one of its three injury rates exceeds the respective plant rate. But, simply listing the hazardous jobs in the order of their injury rates is not sufficient for determining the hazardousness.[3] Man-hours must also be taken into

---

[3]See Definitions, page 6.

consideration if the final object is to be maximum reduction of the plant injury rate. For example, 100 employees in a hazardous job should obviously receive more study than two employees in a job of slightly higher frequency rate. Consequently, keeping in mind that any hazardous job has an injury rate higher than the plant rate, the most hazardous job is defined as that job which, on the completion of its study (i.e., its injury rate reduced to the plant rate), would effect the greatest reduction in the plant injury rate, assuming the injury rates of all other jobs meanwhile remain constant. In other words, elimination of the hazards from the most hazardous job will lower the respective plant injury rate more than the elimination of the hazards from any other job. It is only logical that the safety personnel wish to begin where their work will be most effective. For this reason much has been said about measuring hazardousness.

"H" or the H-number is a number computed to determine the proper hazardousness in keeping with the aforementioned definitions. The higher the H-number the greater the need for immediate study of that job. A job with an "H" of zero will have an injury rate equal to the plant injury rate. Such a job, as well as all jobs with negative H-numbers, is not, by definition, a hazardous job. It should be recognized that this does not preclude the possibility of potentially serious hazards which have not as yet resulted in injuries.

<u>H-Number Derivation:</u>[4]

Derivation of the H-number for the lost-time frequency rate will be considered first.

---

[4]"H" is suggested from the term hazardousness, which it measures.

Let "J" represent a hazardous job in some given plant. There may be any number of employees in that particular job. Assume accident records for a specified time interval in this plant were as follows:

$R_L$ = Plant lost-time frequency rate.

$N$ = Number of lost-time accidents in the plant.

$E$ = Total plant exposure, in man-hours.

$N_{JL}$ = Number of lost-time accidents involving job "J".

$E_J$ = Exposure of job "J" in man-hours.

Next, assume that over a subsequent and equal time interval the lost-time frequency rate of job "J" was reduced to the plant rate, $R_L$. Meanwhile, all other jobs in the plant maintained the same lost-time frequency rate as before. At the duration of this second time interval let

$R'$ = Plant lost-time frequency rate.

$N'$ = Total number of lost-time accidents in the plant.

$N_J'$ = Number of lost-time accidents involving the job "J".

The exposures would of course be the same over both equal time intervals, assuming (1) that injured employees were replaced and (2) that there was no hiring or dismissal of employees.

By computing the plant frequency rate at the end of the second time interval we would find a lower rate resulting. The magnitude of the difference would be solely the effect of bringing job "J" down to the plant rate.

Since our object is to measure the effectiveness, in terms of the plant rate, of injury prevention on various jobs within a given plant, it is seen that all plantwide statistics taken from a different time interval are constant and independent of any given job. From the standard lost-time frequency rate formula,

$$R' = \frac{N' \times 10^6}{E} ,$$

where E and $10^6$ are constant for all jobs over a given time interval.

Therefore,

$$R' \propto N' ,$$

so that R' loses its identity as originally defined. If we let some undefined constant, H, take its place, we have

$$H \propto N' .$$

By definition,

$$N' = N - N_{JL} + N_J' .$$

Once the end of the first time interval is attained, $R_L$, N, and E are all constants. Since N is a constant, then

$$H \propto N_J' - N_{JL} .$$

We are concerned with H only as a relative function. Since it is an undefined constant its algebraic sign is meaningless. Thus we may say

$$H \propto N_{JL} - N_J' .$$

But, from the definitions originally assigned,

$$N_J' = \frac{E_J \times R_L}{10^6} .$$

Therefore,

$$H \propto N_{JL} - \frac{E_J \times R_L}{10^6} .$$

Since these values are all readily attained at the end of the first time interval, we have a workable and useful relation. We will therefore define our H-number for the lost-time frequency rate:

$$H_L = N_{JL} - \frac{E_J \times R_L}{10^6} .$$

The subscript L denotes lost-time injuries.

If it is observed that $\frac{E_J \times R_L}{10^6}$ simply represents the number of lost-time injuries that job "J" will accrue over this time interval when its lost-time frequency rate is reduced to the plant rate, the H-number may very clearly be defined as, the decrease in number of lost-time injuries that would occur in a given job over a given time interval if the frequency rate for that job were reduced to the plant rate in existence at the beginning of the time interval involved.

Interpretation of this H-number would consequently be as follows:

1. The greater the number in a positive direction, the more hazardous the job.

2. The greater the number in a negative direction, the less hazardous the job.

3. A job with a frequency rate equal to the plant rate would have an "H" of zero.

In large plants, where the same job occurs in several departments, this number may be computed for the jobs in each department. Greater exposure and higher reliability can of course be obtained by pooling all like jobs into one calculation.

In plants of more than 10,000 employees it may be necessary to compute the H-number to 5, 6 or even 7 significant figures to reveal differences where job hazardousness is nearly equal. This is quickly done on a comptometer. The apparent small difference should not be interpreted as being insignificant. It is caused, as can be seen from the equation, by extremely large exposures.

The job with the highest "H" should be studied[5] first. This does not mean to imply that only one job should be studied at a time. Such policy would depend on the number of safety personnel available. As the hazards are analyzed and eliminated from the most hazardous jobs the plant rate declines and, by definition, jobs previously considered nonhazardous become hazardous. Thus an endless cycle of improvement is introduced.

In order to minimize accident waste it is also desirable to study jobs having exceptionally high first-aid frequency rates. The first-aid frequency rate will be defined as

$$R_F = \frac{N_F \times 10^6}{E},$$

where $N_F$ = Number of first-aid cases;

---

[5] See Definitions, page 6.

$E$ = Exposure in man-hours;

$R_F$ = First-aid frequency rate.

From a presentation similar to that used in deriving $H_L$,

$$H_F = N_{JF} - \frac{E_J \times R_F}{10^6},$$

where

$H_F$ = H-number for the first-aid frequency rate;

$N_{JF}$ = Number of first-aid cases for the given job;

$E_J$ = Exposure of the job in man-hours.

$R_F$ = Plant first-aid frequency rate.

In order to complete the injury rate picture, a severity H-number, $H_S$, is also computed.

$$H_S = D_J - \frac{R_S \times E_J}{10^3},$$

where

$R_S$ = Plant severity rate;

$E_J$ = Exposure of the job in man-hours;

$D_J$ = Days charged to the given job.

Thus a job may be found hazardous in lost-time accidents and/or first-aid accidents and/or severity. It is seen that emphasis may be placed where most needed. If the frequency rate of a plant is below average for that industry while the plant's severity rate is relatively high, emphasis may be placed on analyzing the jobs at the top of the $H_S$ list.

## COLLECTION OF DATA FOR CALCULATION OF THE H-NUMBER

No attempt will be made here to elaborate on the total makeup of the numerous accident records, forms and reports. To be able to calculate the most hazardous jobs from the formulae given, certain data are required. These data, and the places in the industrial organization where they can most readily be obtained, will comprise this section.

The plant lost-time frequency rate and the plant severity rate are familiar items and can be calculated from any existing accident data. It is essential that all data for the "H" calculations be taken for the same time interval. $E_J$, the total exposure for all positions falling under a given job classification, is a statistic not readily obtained in record systems designed only for the compilation of plant or departmental accident rates. First, the number of significantly different jobs existing in a plant must be determined. The degree of this difference will vary with the size of the plant, the variety of machinery employed and the variety of products involved. A plant with only 20 drill press operators would, to best advantage, use the single job classification of "drill press operator", for these twenty positions. In contrast, a corporation securing job data from several large plants, and with an aggregate of several hundred drill press operators, might well show the following classifications:

Multiple Spindle Drill Press Operator
Radial Drill Press Operator
Single Spindle Drill Press Operator

The classification should be carefully controlled so that only positions of similar activity are included in the same job. Usually the similarity increases with the size of the plant or plants. Sometimes a job will include only a few positions. In such an instance the credibility of the rates computed over any reasonable time interval (one to three years) is likely to be too low to justify the use of the data. In such cases these jobs should be studied for hazards by general job safety analysis.

After the job classifications have been determined and coded each position is then assigned its appropriate code designation. The number of hours of exposure, $E_J$, is then readily obtained from the payroll department. It is suggested that the exposure be assigned the appropriate job at the end of each pay period to avoid a difficult and time-consuming compilation following the complete time interval.

With the exposure available, the only datum necessary for the plant first-aid frequency rate, $R_F$, calculation is $N_{JF}$, the number of first-aid cases for each job. The treatment cards conventionally issued at the first-aid station or hospital normally include this information. The nature of the injury and the job code are the only additional facts needed. This information can easily be added to the regular form.

Filing of these cards by job code simplifies the task of determining $N_{JF}$. Then, $N_F = \quad N_{JF}$. Thus all required data becomes available for computing $R_F$ and $H_F$.

The only data to be collected which are normally not already available at some point in the system are $N_{JL}$ and $D_J$. This information may be gathered by one of three methods: (1) making an extra carbon copy of the accident report, to be filed in the safety office by job;

(2) initiation of a new form; (3) inclusion of this information in an existing form or report. The first method may even exclude the "additional copy" if there is no pertinent reason for some other filing order, i.e., by date, name, payroll number, etc.

Through filing all lost-time accident reports by code, $N_{JL}$ is found by simple count. The time charges for each accident must necessarily be added separately in determining $D_J$.

Summary of Data Required for Computation of H:

$H_L$:
- $E_J$, exposure of each job, in hours.
- $N_{JL}$, number of lost-time accidents for each job.
- $R_L$, the plant lost-time frequency rate.

$H_F$:
- $E_J$, exposure of each job, in hours.
- $N_{JF}$, number of first-aid cases for each job.
- $R_F$, the plant first-aid frequency rate.

$H_S$:
- $E_J$, exposure of each job, in hours.
- $D_J$, days charged to each job.
- $R_S$, the plant severity rate.

Several unavoidable weaknesses are found in reliance on past records for accident analysis. Inasmuch as all records are "past records", they must be used. Personnel using records should be aware of the potential inconsistencies and changes which can lead to inaccurate interpretation. When major, or even a large number of minor changes are incorporated in processes, products, machines or environment, accident records may lose much of their value by reason of variations in the operational characteristics. The number of accidents for a job over some time interval would be less significant for purposes of analysis if the operations and activities of that job were changed several times during that time interval. Similarly, the introduction of a training program, or of an intensified safety program would tend to change the interpretation of total data. A high turnover for either workers or foremen would also lessen the reliability of the data accrued. Consequently, the time interval for the accumulation of data should be selected so as to afford a maximum degree of homogeneity.

## CREDIBILITY OF ACCIDENT RATES

"H" is basically derived from the frequency and severity rates; therefore, the probable error of "H" is identical with the probable error of the accident rates. Such a measure may be derived from the Poisson Exponential, a fundamental application of what is commonly referred to as the "law of averages". However, the Poisson Theorem assumes random, or "chance" distribution. Greenwood and Woods,[6] and later Newbold,[7] proved statistically that accident frequency of relatively large samples was not a random occurrence. The difference between the chance curve and the actual curve has been attributed to "accident proneness". It will suffice to accept this as the definition of accident proneness without delving into the causation factors. More than a hundred "personal factors", "human traits", "psychological factors", etc., have been shown, experimentally and otherwise, to contribute to accident proneness.[8] The intent of this thesis precludes further consideration of these causes. It will simply be recognized that when accident proneness is present, by definition, the frequency

---

[6] Major Greenwood and H. M. Woods, A Report on the Incidence of Industrial Accidents upon Individuals, with Special Reference to Multiple Accidents (Report No. 4 of the Industrial Fatigue Research Board, 1916).

[7] E. M. Newbold, "Practical Applications of the Statistics of Repeated Events, Particularly to Industrial Accidents," Royal Statistical Society Journal, 90:487-535, 1927.

[8] C. V. Culbertson, "A Primary Source Bibliography of the Psychological Phases of Industrial Safety and Accident Analysis for the Period 1930-1950," (unpublished paper, Psychology Department, Georgia Institute of Technology, Atlanta, March, 1950).

distribution will tend to vary from a chance distribution. Since the objective is to identify hazards which are an integral part of the job, randomness of accident incidence shall be assumed. Interpretation of results and consideration of the effect of accident proneness on these results are discussed on page 37.

The measure of probable error of the frequency rate to be derived from the Poisson Law shall be referred to as "credibility". Thus credibility is defined as <u>a measure of probability that the true frequency rate lies within certain defined limits of the computed rate, for a given number of injuries</u>. Discussion shall be limited to the frequency rate to avoid confusion. The "true" frequency rate would be the rate resulting from data taken over an infinite time interval. For two computed rates to have equal credibility the probability that the true rates lie within the given confidence limits of the computed rate is the same. On the other hand if rate <u>A</u> is more credible than rate <u>B</u>, then the limits of <u>A</u> and the probability of <u>B</u> are smaller.

It has been stated repeatedly in safety literature that the credibility of the accident rates increases with increased exposure. Little consideration has been given to the effect of the number of injuries on this credibility. The purpose of this section is to verify the contention that the credibility of a computed frequency rate is dependent on the number of injuries as well as on the exposure in man-hours. If this contention is true it would follow that, as the frequency rate increases, equally credible results are obtained from decreasing exposures.

In the discussion to follow,

$F_c$ = computed lost-time frequency rate.

$F_t$ = true lost-time frequency rate (infinite time interval).

$E$ = exposure in man-hours.

$N_c$ = actual number of lost-time injuries experienced.

$N_t$ = number of lost-time injuries that would have occurred had the frequency rate been equal to $F_t$.

The "true frequency rate" would be the rate computed from an infinite exposure provided the conditions in the plant (personnel, characteristics of machinery, training, products, processes, etc.) remained unchanged. $N_t$ would be the number of injuries sustained during some exposure, E, when the rate equals $F_t$.

For this presentation, the probability that $F_t$ is within certain defined limits of $F_c$ shall be taken as 80/100. The confidence limits will be determined by $N_c$ or the E under consideration.

These limits will be defined as a percentage of $F_c$ rather than in frequency rate units. Using frequency rate units (i.e., to say that $F_c$ is within so many frequency rate units of $F_t$) would cause the probability to vary directly with the frequency rate. The probability that a frequency of $6 \pm 5$ would fall within its limits is much greater than for a frequency of $40 \pm 5$. Since it is desired to compare frequency rates of various magnitudes, but of equal credibility, use of frequency rate units would only complicate the equation.

The lower limit is always smaller than the upper limit because negative frequency rates do not exist. There is a lower limit to the possible range of $F_c$ (zero) while, theoretically, there is no upper limit to this range. Therefore, as $F_c \rightarrow 0$, the lower limit will of course approach $F_c$.

The curves used for plotting Figures 1-3 were taken from A Guide to Utilization of the Binomial and Poisson Distribution in Industrial Quality Control.[9] Figure 5 is a photostat of these curves.

Figure 1 shows the confidence limits of $N_t$ for a given $N_c$. The probability for all curves to be presented is .800. Therefore, in plotting Figure 1 from the curves in Figure 5, the .9 and .1 probability limits were used. It may be read from Figure 5 that the probability is 9 out of 10 that the number of occurrences is less than the value on the .9 probability limit curve. Similarly the .1 probability limit curve would exclude the lower 10 per cent of the occurrences. Therefore all values contained within these two limits would include 80 per cent of the possibilities. Hence a probability of .80 ($P = .80$) is used. In plotting Figure 1 the abscissa would be $N_t$ and the ordinate $N_c$.

One sample plot will be explained. For $N_c = 20$, note the two points where 20 occurrences (horizontal line on Figure 5) intersect the .9 and .1 probability limit curves. These points, read on the abscissa, are seen to be approximately 15 and 26.5. These two values of $N_c$ are then plotted on Figure 1. Therefore it may be stated that for an experience of 20 injuries, notwithstanding accident proneness, the chances are 8 out of 10 that there might have been from 15 to 26 injuries under the same conditions. Note that the limits, defined as a percentage of $N_c$, become considerably smaller when $N_c$ is increased. It is seen that exposure has no effect on this trend — it is omitted

[9] Holbrook Working, A Guide to Utilization of the Binomial and Poisson Distributions in Industrial Quality Control (Stanford, California: Stanford University Press, 1943), p. 12.

from the picture altogether. This tightening of limits holds true for any value of $\underline{E}$. Thus, for an experience of 5 injuries, the probability is .80 that $N_t$ lies between 2.65 and 8.80 (Figure 2 is included for easier interpretation of $0 < N_c < 5$). This degree of credibility may be symbolized as $P_5\ (2.65 < N_t < 8.80) = .80$. The subscript 5 designates $N_c$.

Figure 3 is plotted as follows: For $N_c = 5$ it was shown that the lower and upper limits respectively were 2.65 and 8.80. Therefore, $\frac{5.0 - 2.65}{5.0} = .47$. Thus the lower limit, as measured from $N_c$, represents a possible error of 47 per cent of $N_c$. Care must be taken not to confuse this interpretation with the fact that, for $N_c = 5$, the lower limit is equal to $.53\ N_c$. In this latter case (this method will be used in designating credibility) the per cent of $N_c$ is measured from zero. Brackets in Figure 2 are included to clarify this difference. For $N_c = 5$ on Figure 3, 47 per cent is plotted. Also, for the upper limit, $\frac{8.80 - 5.0}{5.0} = .76$, and 76 per cent is also plotted for $N_c = 5$. Note that when measured from zero rather than from 5 this upper limit would be $1.76\ N_c$. The curves of Figure 3 represent points measured from $N_c$, not from zero. All points were plotted in accordance with the above procedure.

Figure 3 clearly illustrates two allegations: (1) the upper limit, as a per cent of $N_c$, is slightly higher than the lower limit; (2) as $N_c$ increases, the limits become more narrow, i.e., decrease, as a per cent of $N_c$. Note that as $N_c$ increases from 10 to 30 the upper limit decreases from 48 to 26 per cent while the lower limit decreases from 35 to 21 per cent. This holds true regardless of exposure.

One is justified in questioning the merit of such wide limits and low probability. As the proof of our contention is presented, it will be seen that any increase in credibility, either through higher probability or more narrow limits, would be useless. If a probability of .98-.99, ordinarily acceptable for scientific investigation, were employed, the confidence limits would be so extended as to render $N_c$ practically meaningless. Also, confining the limits to a much smaller per cent of $N_c$ would necessarily yield a probability so low that it would become useless. It is evident that the frequency rate is indeed an inadequate measure of safety performance.

The probability (.80) and the credibility chart presented in this thesis are not particularly recommended as being the measure of accuracy required in industry. The accompanying figures were chosen primarily for illustration. As will be seen later, a table such as Table I would be needed for each value of $N_c$.

Since $F_c$ is directly proportional to $N_c$ we may conclude that, for a constant probability and exposure, $F_c$ becomes more credible (more narrow limits) as $N_c$ increases. But it is desired to hold the credibility constant for different values of $F_c$. It has been shown that for $N_c = 5$, $P_5(2.65 < N_t < 8.80) = .80$. This is true for any experience of 5 injuries, regardless of E. By varying E, we may vary $F_c$ and retain this defined credibility, which may also be written $P_5(.53\ F_c < F_t < 1.76\ F_c) = .80$, since the frequency is always directly proportional to the number of injuries for a given E. This designation will be used to define a given credibility.

Table I is computed as follows:

$N_c = 5$ for all values of $F_c$.

For $E = 1{,}000{,}000$ man-hours, $F_c = N_c = 5$.

For $E = 200{,}000$ man-hours, $F_c = 5 \times 10^6/200{,}000 = 25$.

TABLE I

CREDIBILITY TABLE

| $P_5(.53\ F_c < F_t < 1.76\ F_c) = .80$[10] | | | | | |
|---|---|---|---|---|---|
| $F_c$ | E(man-hours) | $F_c$ | E(man-hours) | $F_c$ | E(man-hours) |
| 5 | 1,000,000 | 21 | 238,000 | 36 | 139,000 |
| 6 | 830,000 | 22 | 227,000 | 37 | 135,000 |
| 7 | 720,000 | 23 | 217,000 | 38 | 132,000 |
| 8 | 630,000 | 24 | 208,000 | 39 | 128,000 |
| 9 | 560,000 | 25 | 200,000 | 40 | 125,000 |
| 10 | 500,000 | 26 | 192,000 | 41 | 122,000 |
| 11 | 455,000 | 27 | 185,000 | 42 | 119,000 |
| 12 | 417,000 | 28 | 179,000 | 43 | 116,000 |
| 13 | 384,000 | 29 | 172,000 | 44 | 114,000 |
| 14 | 357,000 | 30 | 167,000 | 45 | 111,000 |
| 15 | 333,000 | 31 | 161,000 | 46 | 109,000 |
| 16 | 313,000 | 32 | 156,000 | 47 | 106,000 |
| 17 | 294,000 | 33 | 152,000 | 48 | 104,000 |
| 18 | 278,000 | 34 | 147,000 | 49 | 102,000 |
| 19 | 263,000 | 35 | 143,000 | 50 | 100,000 |
| 20 | 250,000 | | | | |

Uses and interpretations of this table are thoroughly discussed later. At present it is included only to demonstrate its usefulness in determining necessary exposures for a given credibility. For example, a frequency rate of 40 computed on 125,000 man-hours exposure is just as credible as a frequency of 10 taken from 500,000 man-hours.

[10]The statement of credibility of this table.

Figure 4, constructed from Figures 1 and 2 for a constant $F_c$, shows that the rate of change of the limits is greatest over the range of exposure between zero and one million man-hours. Figure 4 also demonstrates the popular theory that as exposure is increased, credibility is increased. An interesting conclusion on this theory may be observed readily from the curves. Apparently increasing the exposure beyond three million (3,000,000) man-hours has a negligible effect on the credibility, since beyond this figure the confidence limits are nearly parallel to $F_t$.

Implications and Uses of Credibility:

As Blake[11] has written, "some authorities consider 1,000,000 man-hours the minimum exposure for which the frequency rate may be accepted as a reliable gage of safety performance during the period in question". In concluding, this exposure is accepted as a recommended minimum. As previously proved, taking some constant exposure for all frequency rate calculations would not yield equally credible results. For a given probability, and a constant exposure, the confidence limits of the computed rate would decrease as $F_c$ (or N) increased. If the limits and the exposure were held constant, then the probability would be directly proportional to the frequency rate.

Therefore, if frequency rates are to represent equivalent accuracy of measure, it must be recognized that smaller exposures may be used for the more hazardous experiences. This is clearly demonstrated in Table I.

---

[11] R. P. Blake, Industrial Safety (New York: Prentice-Hall, Inc., 1943), p. 36.

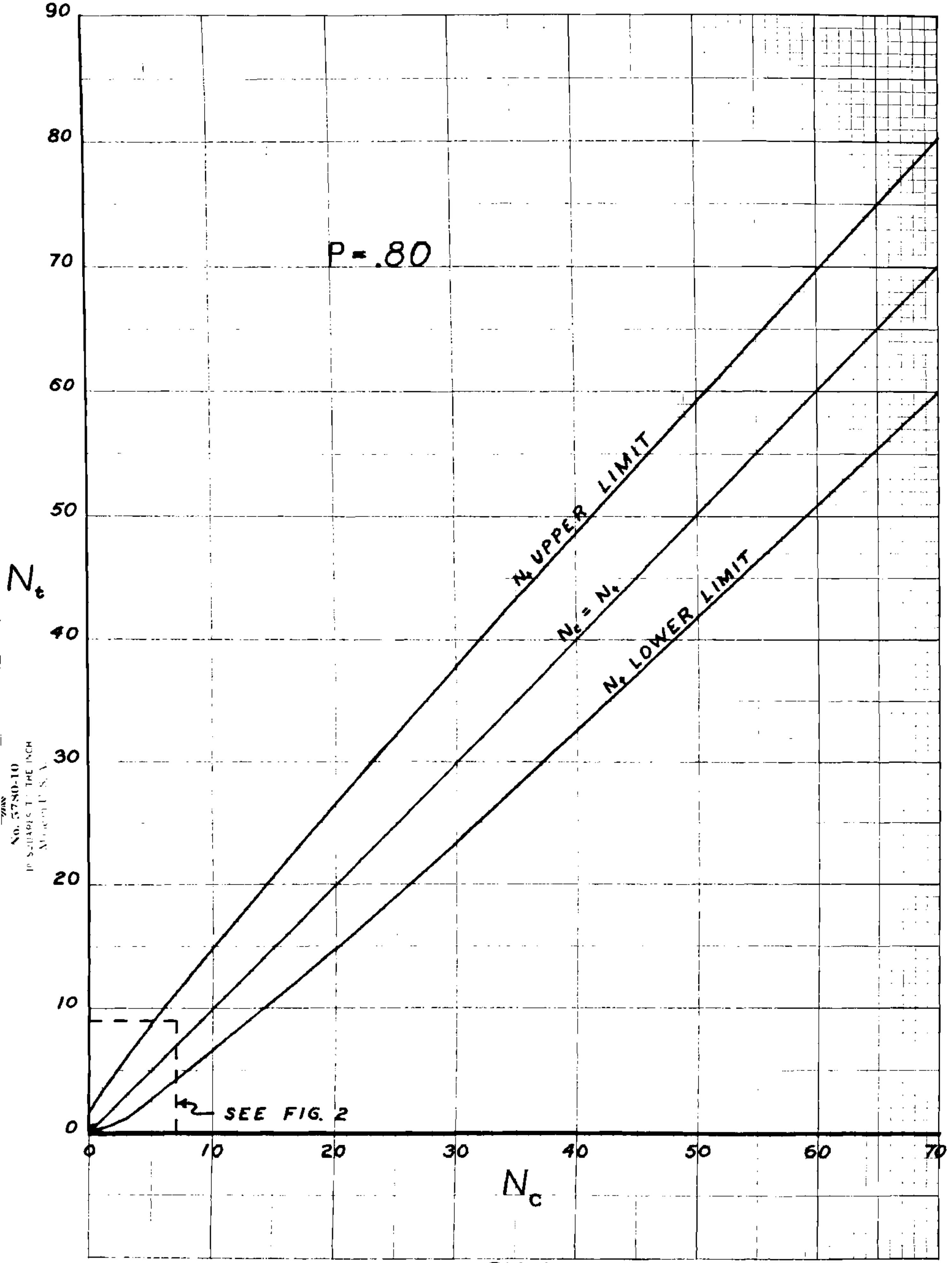
P = .80
$N_t$ UPPER LIMIT
$N_c = N_t$
$N_t$ LOWER LIMIT
SEE FIG. 2
$N_t$
$N_c$
0
10
20
30
40
50
60
70
80
90

FIG. 1

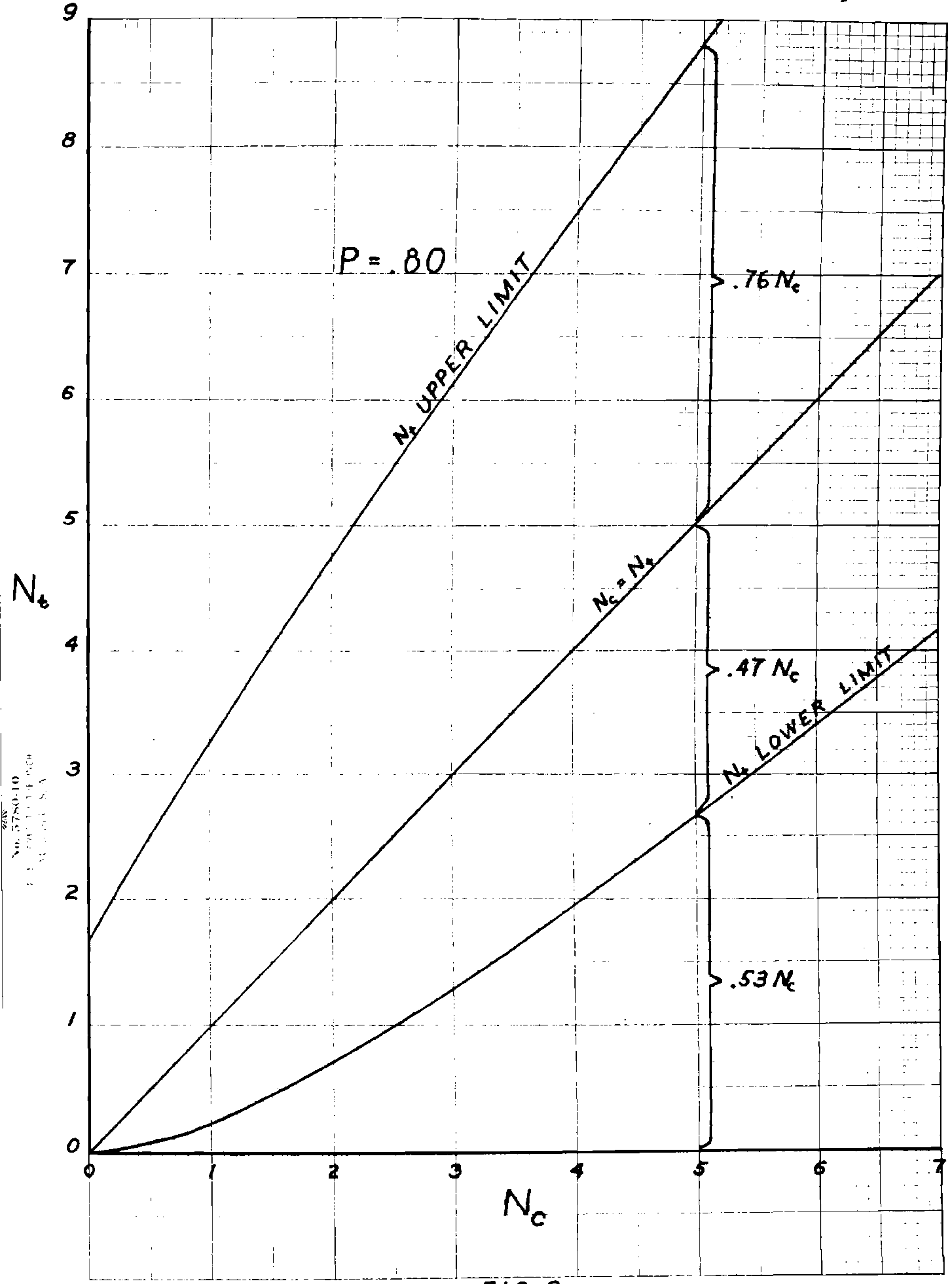
P = .80
$N_t$ UPPER LIMIT
$N_c = N_t$
$N_t$ LOWER LIMIT
.76 $N_c$
.47 $N_c$
.53 $N_c$
$N_t$
$N_c$
0
1
2
3
4
5
6
7
8
9

FIG. 2

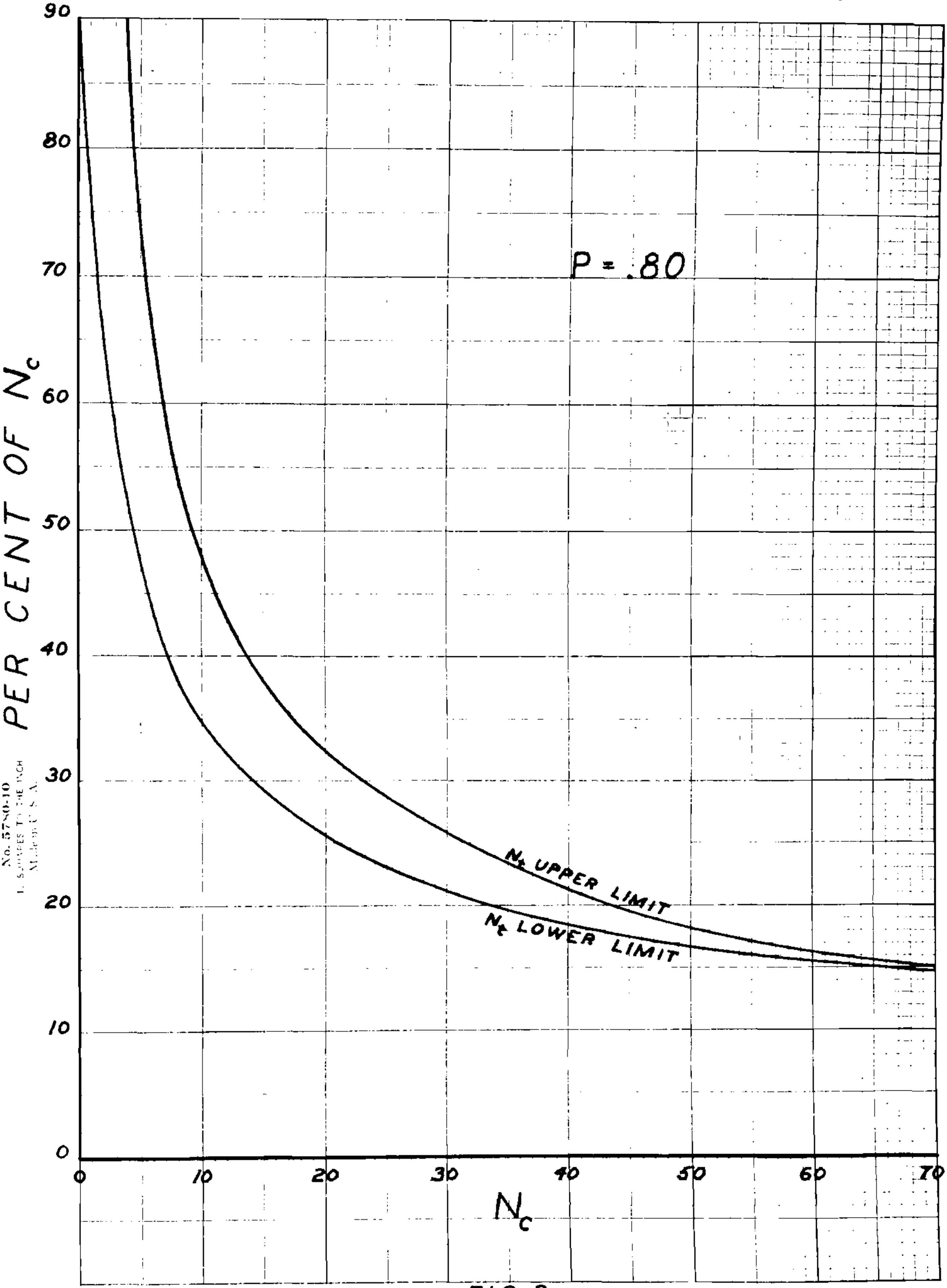
P = .80
PER CENT OF $N_c$
$N_c$
$N_t$ UPPER LIMIT
$N_t$ LOWER LIMIT
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70

FIG. 3

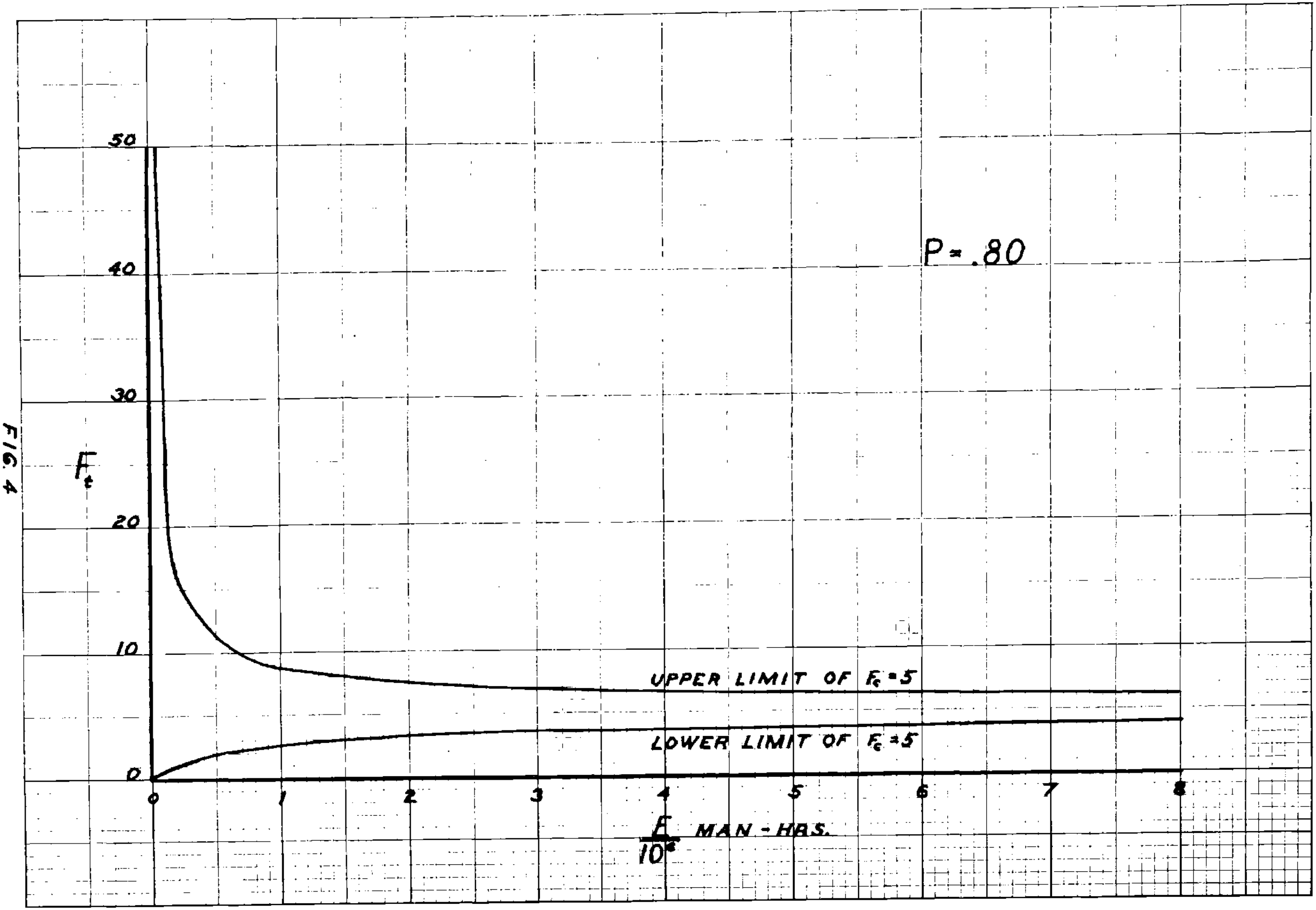
P = .80
$F_t$
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
UPPER LIMIT OF $F_c$ = 5
LOWER LIMIT OF $F_c$ = 5
$\frac{E}{10^6}$ MAN - HRS.

FIG. 4

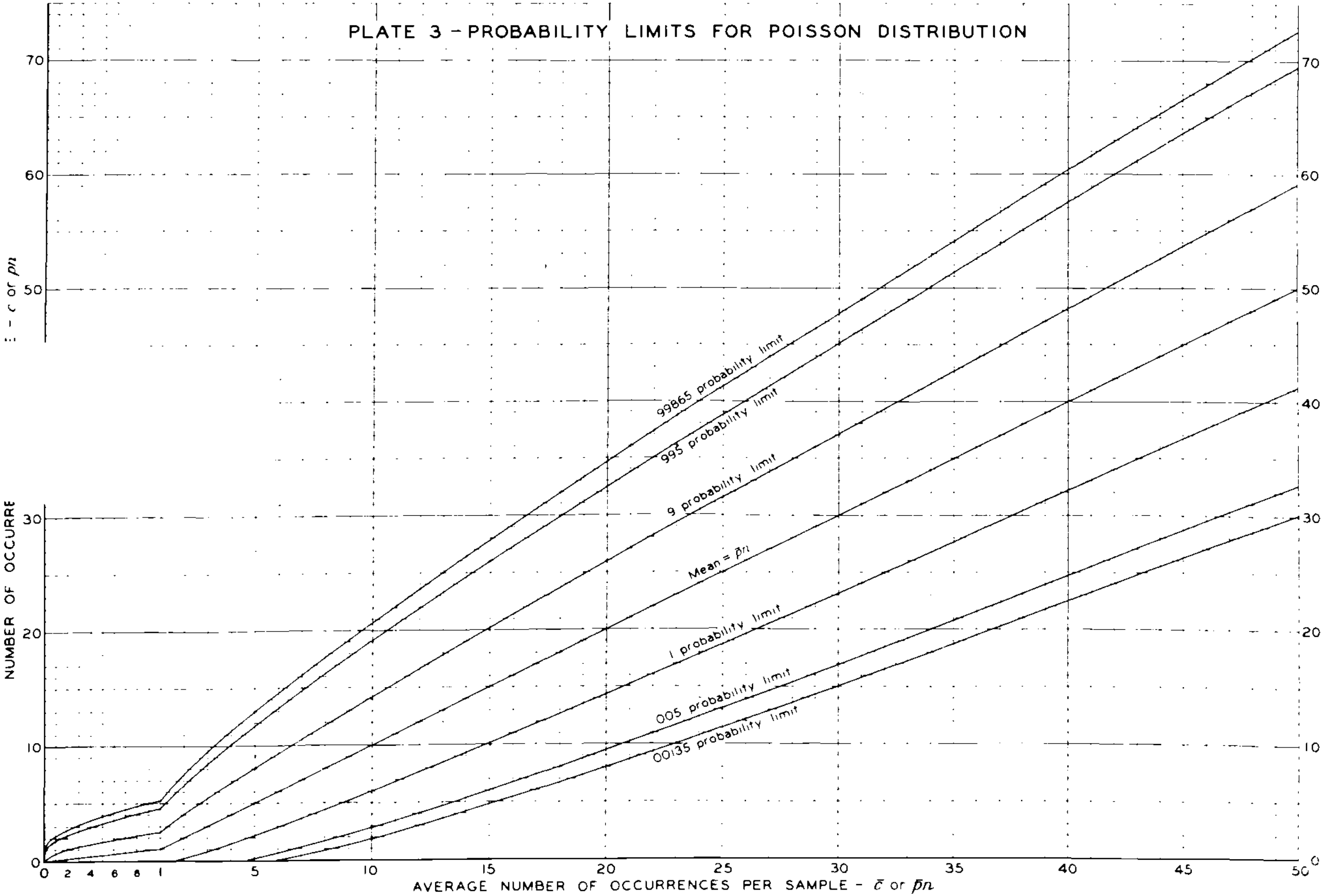
PLATE 3 - PROBABILITY LIMITS FOR POISSON DISTRIBUTION
NUMBER OF OCCURRE
- c or pn
AVERAGE NUMBER OF OCCURRENCES PER SAMPLE - $\bar{c}$ or $\bar{p}n$
99865 probability limit
995 probability limit
9 probability limit
Mean = $\bar{p}n$
1 probability limit
005 probability limit
00135 probability limit
0
10
20
30
40
50
60
70
0 2 4 6 8 1 5 10 15 20 25 30 35 40 45 50

FIG. 5

With reference to Table I, it cannot be assumed that the frequency rate of a job is known before statistics on that job are attained. Such an assumption would dismiss the necessity of investigation. Thenceforth the question arises, "how can the exposure required for a given credibility be predetermined from Table I when no frequency rate is available at the beginning of the time interval of exposure?"

It is not necessary to know even the approximate frequency rate in advance, as long as cumulative rates are computed. From Table I, if 100,000 man-hours exposure have accrued and the computed frequency rate is 50 or higher, action may be taken without awaiting further proof of credibility. If the $F_c$ is less than 50, additional exposure is required to attain the desired credibility. Exposure should continue until the computed frequency rate is equal to or greater than the $F_c$ (left column, Table I) opposite the exposure used in making the calculation. It must be remembered that Table I is valid only for $N = 5$. If an additional injury occurs before the required exposure is attained, credibility must be checked from a similar table set up on the basis of $N = 6$. From Figure 1 the credibility of such a table would be $P_6(.58\ F_c < F_t < 1.67\ F_c) = .80$. Since the limits are tighter, less exposure would be required to attain the same credibility as before. Thus, as tables for progressively higher $N_c$'s are formulated, the necessary exposure for constant credibility decreases further. The limits for the credibilities of additional tables may be read from Figure 3. Let L be the lower limit from Figure 3, and U be the upper limit. Then (1.0 - L) and (1.0 + U) would fix the credibility limits — e.g., for $N_c = 10$ the lower limit is $(1 - .35)F_c$ and the upper limit is $(1 + .48)F_c$, or $.65\ F_c$ and $1.48\ F_c$. The credibility would be designated as $P_{10}(.65\ F_c < F_t < 1.48\ F_c) = .80$.

In Table I, $F_c = 5$ was selected as the base since it is the intention of this treatise to study hazardous jobs. The probability of ever studying a job of frequency rate less than 5 is extremely remote. On the other hand, job frequency rates between 25 and 100 are not at all uncommon in industry, especially when the most hazardous jobs are being surveyed. Let us consider a plant frequency rate of 15. Removal of all office workers and other relatively "nonhazardous" jobs would conceivably double the frequency rate. If the most hazardous job of all those remaining were reviewed, it should not be exceptional to find a job lost-time frequency rate of 100 or even higher.

Since Table I is for illustrative purposes only, the highest $F_c$ appearing is 50. The extent to which a particular plant may wish to extend the credibility tables would depend on the hazardousness of the jobs under consideration. There is no limit to the reduction in exposure that can be accepted for an equally credible rate. Going to extremes, a lost-time frequency rate of 1000 computed on 5000 man-hours exposure would have the credibility designated in Table I. But it is recalled that the probability is .80. Where a job suffers a lost-time accident its first hour of exposure, or where a catastrophe injures a large number of workers simultaneously, obviously a noncredible rate will be obtained. Incidents such as these account for the 2 out of 10 times that the $F_t$ does not lie within the given limits. Increasing the probability is one means of increasing the size of catastrophe that can be included within the limits for a given credibility.

As stated on page 22 the Poisson distribution is seldom found in industry due to the presence of accident proneness. Regardless of the degree of accident proneness existing in a given situation, it will not affect the effectiveness of the aforementioned tools in identifying the most hazardous jobs. Interpretation of results should not be confined to calculations. When a job classification reveals a high lost-time frequency the accident reports of that job should be carefully scrutinized for significant information. If it is found that one worker is responsible for a large number of the accidents pertaining to that job while the remainder of the accidents are spread out over all the other workers, this distribution should be carefully considered. A number of possibilities exist: (1) he may be working -- on the same job as the others, of course -- in a more hazardous environment; (2) his machine may be out of adjustment, need repair or maintenance; (3) his training may have been inadequate, or he may have been placed in a job for which he is not fitted and to which he cannot adapt himself; (4) he may be "accident-prone". Certainly the tabulation itself would not be sufficient evidence for classification of the worker as an "accident-prone".

It may be found that, by omitting all of this one worker's accidents from the record, the job would no longer be classified as hazardous. In any event, regardless of the causes of the injuries, the information resulting from this procedure will indicate to the safety personnel where a study is needed.

The credibility of the first-aid frequency rate and of the severity rate has been omitted for the sake of clarity. As explained on page 10 the ratio of first-aid injuries to lost-time injuries varies widely from job to job. Table I could be used directly for both lost-time frequency and first-aid frequency rate calculations where a ratio of 1/1 existed. In order to use this table for any first-aid rate it would of course be necessary to factor this rate by the known ratio.

If this ratio is not known, and no records have been kept, it may be found, for a given job, only by accumulating several hundred thousand man-hours exposure. Once it has been determined, Table I may be used for any ratio by juggling the first-aid frequency rate formula. Where a ratio of 60/1 is discovered, computing the first-aid frequency rate from $\frac{N_F \times 6 \times 10^4}{E}$ will give a rate and an exposure which may be matched for credibility in Table I. Obviously this formula would be used only for purposes of determining credibility. If a different first-aid frequency rate formula were used for each job or occupation, there would remain no basis of comparison for locating the most hazardous job.

The credibility of severity presents a much more complex problem. In the small plants it is next to hopeless, especially if the extreme fluctuation in time charges resulting from a fatality is occasionally introduced. A sample including 1000 injuries is generally accepted as reliable. It would take a small plant of 200 employees, single shift, over 1600 years to accrue sufficient data, assuming a lost-time frequency rate of 15, for computation of an acceptable severity rate. Accruing credible data in even the larger plants and/or corporations can become a lengthy, time-consuming proposition. Twenty thousand workers representing a lost-time frequency rate of 15 would take a quarter of a century to accumulate 1000 lost-time injuries. Even though this handicap exists, the usefulness of the severity rate should not be overlooked. To make the unqualified statement that all severity rates must be based on 1000 accidents to attain comparable credibility would again be disregarding the components of the numerator of the severity rate equation. Again the seriousness (as measured by time charges) of the accidents typifying a given job must be considered. A job exhibiting a high ratio of fatalities to lost-time injuries might easily demand an experience of 1000 accidents to yield a defined credibility. A second job, however, wherein fatalities are next to nonexistent, might show an equally credible severity rate through experiencing only a small fraction of a thousand accidents. It is outside of the intentions of this thesis to delve further into severity credibility.

It should at least be kept in mind that, where no fatalities have occurred -- and, it might be added, where they seldom do occur -- a severity rate based on only 50 or 100 injuries may well yield results of considerable significance. Though the $H_S$ derived therefrom may not be as credible as desired, the jobs of relatively high severity will be identified. As the sample becomes smaller, there is greater need for careful interpretation of the records and the proportion of fatalities.

Credibility of H:

If the H-numbers ($H_L$, $H_F$, and $H_S$) are fully comprehended, it is observed that the credibility of H is simply the credibility of the accident rate from which it was derived. If the lost-time frequency rate of job A represents a certain credibility, then the hazardousness of that job is just as credible. The confidence limits will not be an identical quantity due to the change in units, but the proportion of these limits will remain the same, when defined as a percentage of H.

A similar comparison may be made for the credibility of $H_F$ and $H_S$.

When identifying hazards by job smaller exposures are unavoidable. However, it has been shown that, for the most hazardous jobs — the ones with which we will be working — considerably less exposure is required for a given credibility. When working with small exposures it is very important that the credibility of the H-number be known.

## SMALL EXPOSURE FREQUENCY

In computing accident statistics from job classifications rather than from plantwide or departmental data, the exposure will always be smaller in a single plant. For a large corporation or a chain of plants, however, the reverse may hold true. In dealing with smaller exposures the credibility of the frequency rate soon exceeds its lower limit. The maximum time interval for an initial exposure accrual varies in accordance with the nature of the industry. Some plant organizations and operations remain virtually unchanged for many years, while, in contrast, other plants are continuously changing their processes.

Assuming an average initial exposure of 300,000 man-hours is required for acceptable credibility in a given situation, the following table is quickly computed:

| Shifts per 24 hour period | No. of employees required to meet the minimum exposure |
|---|---|
| 1 | 50 |
| 2 | 25 |
| 3 | 17 |

In some large plants and in most small plants there will be job classifications including less than seventeen employees. Even more commonly single shift plants with job classifications of less than 50 positions would be found. Since it is not advisable to use uncredible frequency rates, a need exists to alleviate this small exposure problem. As was discussed on page 19, careful interpretation of available data combined with inspection consists of one possible solution. Another method, which is beyond the scope of this thesis, shall be suggested but not followed to completion.

It has been shown on page 37, that within certain limits some approximate ratio exists between first-aid and lost-time injuries for every job.[12] Let this ratio be represented by F/L. In most cases it would result in a number larger than unity. A job including the use of numerous hand tools, yet lacking in more serious hazards, might be typical of a high F/L ratio. On the other hand, a job such as the erection of aluminum scaffolding would be representative of a very low F/L ratio. After accident records have been kept for several years the ratio will take shape. As the data accumulate, F/L will be more accurate. When this ratio assumes some proportion of constancy it would be ready for adoption.

Once established, F/L could be used to "foresee" the lost-time accident trend. Thus action could be taken before the total man-hours of exposure were attained. An increase in the rate of first-aid cases would forewarn of an impending lost-time injury. It is only logical to thereby conclude that some factor which is causing more accidents has been introduced.

There remains, of course, the possibility that the "factor" introduced may only be changing the F/L ratio by increasing the number of first-aid cases. This would not necessarily indicate additional potential lost-time injuries. Even so, a study would be wise to determine why the number of first-aid cases increased.

---

[12] C. S. Slocombe, Personnel Journal, 20:48, 1941.

BIBLIOGRAPHY

BIBLIOGRAPHY

Blake, R. P., Industrial Safety. New York: Prentice-Hall, Inc., 1943. 435 pp.

Fry, Thornton C., Probability and Its Engineering Uses. Seventh printing; New York: D. Van Nostrand Co., Inc. 476 pp.

Greenwood, M. and H. M. Woods, A Report on the Incidence of Industrial Accidents upon Individuals, with Special Reference to Multiple Accidents. Report No. 4 of the Industrial Fatigue Research Board, 1916.

Newbold, E. M., "Practical Applications of the Statistics of Repeated Events, Particularly to Industrial Accidents," Royal Statistical Society Journal, 90:487-535, 1927.

President's Conference on Industrial Safety. Washington, D. C.: U. S. Government Printing Office, March 1949. 362 pp.

Shartle, C. L., Occupational Information. New York: Prentice-Hall, Inc., 1946. 339 pp.

Tiffin, Joseph, Industrial Psychology. Second edition; New York: Prentice-Hall, Inc., 1947. 553 pp.

Working, Holbrook, A Guide to Utilization of the Binomial and Poisson Distributions in Industrial Quality Control. Stanford, California: Stanford University Press, 1943.